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AIRBORNE RADIOMETRIC SNOW GAGE

DEADMAN CREEK SITE - AERIAL VIEW

FIELD TESTS WINTER 1970-1971

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SPUR PARK SITE - GROUND VIEW

Prepared by

U. S. DEPARTMENT of AGRICULTURE ★ SOIL CONSERVATION SERVICE

and

MONTANA AGRICULTURAL EXPERIMENT STATION

AUGUST 1971

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AIRBORNE RADIOMETRIC SNOW GAGE

August 1971

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AIRBORNE RADIOMETRIC SNOW GAGE

Introduction

At the completion of a two-year project conducted by the Montana Agricultural Experiment Station - sponsored jointly by the Atomic Energy Commission and Bonneville Power Administration - to develop and reduce to practice, a prototype system for the airborne (A/B) measurement of the water equivalent stored in a snowpack, it was decided to further field test the gage using additional snow course sites.

Three sites with existing Soil Conservation Service snow pillow installations were selected for this field test. The sites were Spur Park, elevation 8100', expected snow-water equivalent in thirty (30) inch range; Deadman Creek, elevation 6450', expected snow-water equivalent of less than 20"; and Lick Creek, elevation 6860', and expected snow-water equivalent less than 20".

Spur Park and Deadman Creek are in the Little Belt Mountains, northeast of White Sulphur Springs. Lick Creek is in the Gallatin mountain range, south of Bozeman. Lick Creek was used for field evaluation in the earlier project. General locations are shown in Figure 1.

Theory, system-design parameters, and tables are fully covered and/or presented in U. S. Atomic Energy Commission publication RLO-2061-1, "An Airborne Radiometric Snow Survey System, September 1970," available from the National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22151, for $3.00. The report is referenced for details rather than including them herein.

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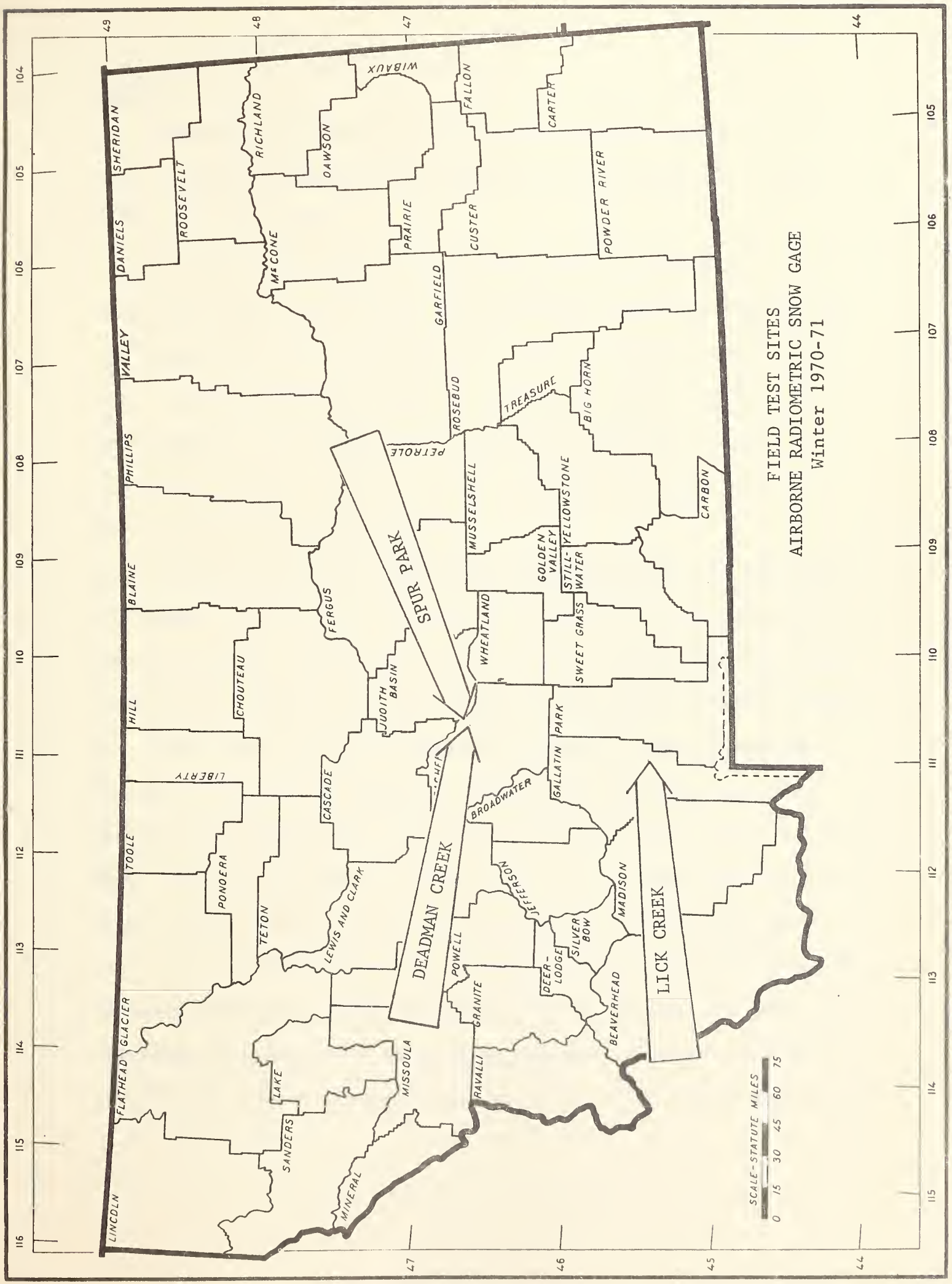
MONTANA
FIELD TEST SITES
AIRBORNE RADIOMETRIC SNOW GAGE
Winter 1970-71
SPUR PARK
DEADMAN CREEK
LICK CREEK
SHERIDAN
DANIELS
VALLEY
PHILLIPS
BLAINE
HILL
LIBERTY
TOOLE
GLACIER
FLATHEAD
LINCOLN
ROOSEVELT
RICHLAND
McCONE
WIBAUX
DAWSON
PRAIRIE
FALLON
CARTER
CUSTER
POWDER RIVER
GARFIELD
ROSEBUD
PETROLE
TREASURE
BIG HORN
MUSSELSHELL
YELLOWSTONE
CARBON
GOLDEN VALLEY
STILL-WATER
SWEET GRASS
WHEATLAND
FERGUS
CHOUTEAU
JUDITH BASIN
CASCADE
PARK
GALLATIN
BROADWATER
PONDERA
TETON
LEWIS AND CLARK
JEFFERSON
MADISON
POWELL
SILVER BOW
DEER-LODGE
GRANITE
BEAVERHEAD
LAKE
MISSOULA
RAVALLI
SANDERS
MINERAL
SCALE-STATUTE MILES
0 15 30 45 60 75

FIGURE 1.

Results

Correlations between the snow pillow, snow tube and A/B method are presented in graphical form showing water equivalent vs. time, in Figures 2, 3, 4, and 5.

A tabulation of data is presented in Table 1 and Table II. The final net count (A/B) from the data reduction sheets and computations is "normalized" giving the zero water count a value of 1.00. In this way a single calibration curve can be used instead of one for each snow course. It is necessary, however, to use different curves for different isotopes - in this instance Co^{60} for Spur Park, and Cs^{137} for Lick Creek and Deadman Creek.

The water equivalent graphs and correlation plots for Spur Park and Deadman Creek reveal that nearly all samples for the two systems remained within a few percent of each other. It was noted that Lick Creek did not track in the same manner as Spur Park and Deadman Creek.

There was a period of unseasonably moderate temperatures and rainfall at the end of January 1971 and it is believed this period changed the relationship between the pillow, snow course and A/B snowpack. The A/B emplacement at Lick Creek is on a shaded area, more so than the snow course or snow pillow and meltout is at a later date.

In the 1969-70 season the radiometric source was placed after the snowpack had begun. A snow blower was used to replace snow over the emplacement comparable to surrounding snowpack. However, this was overdone and snow tube measurements on May 13, 1970 indicated about 4.5

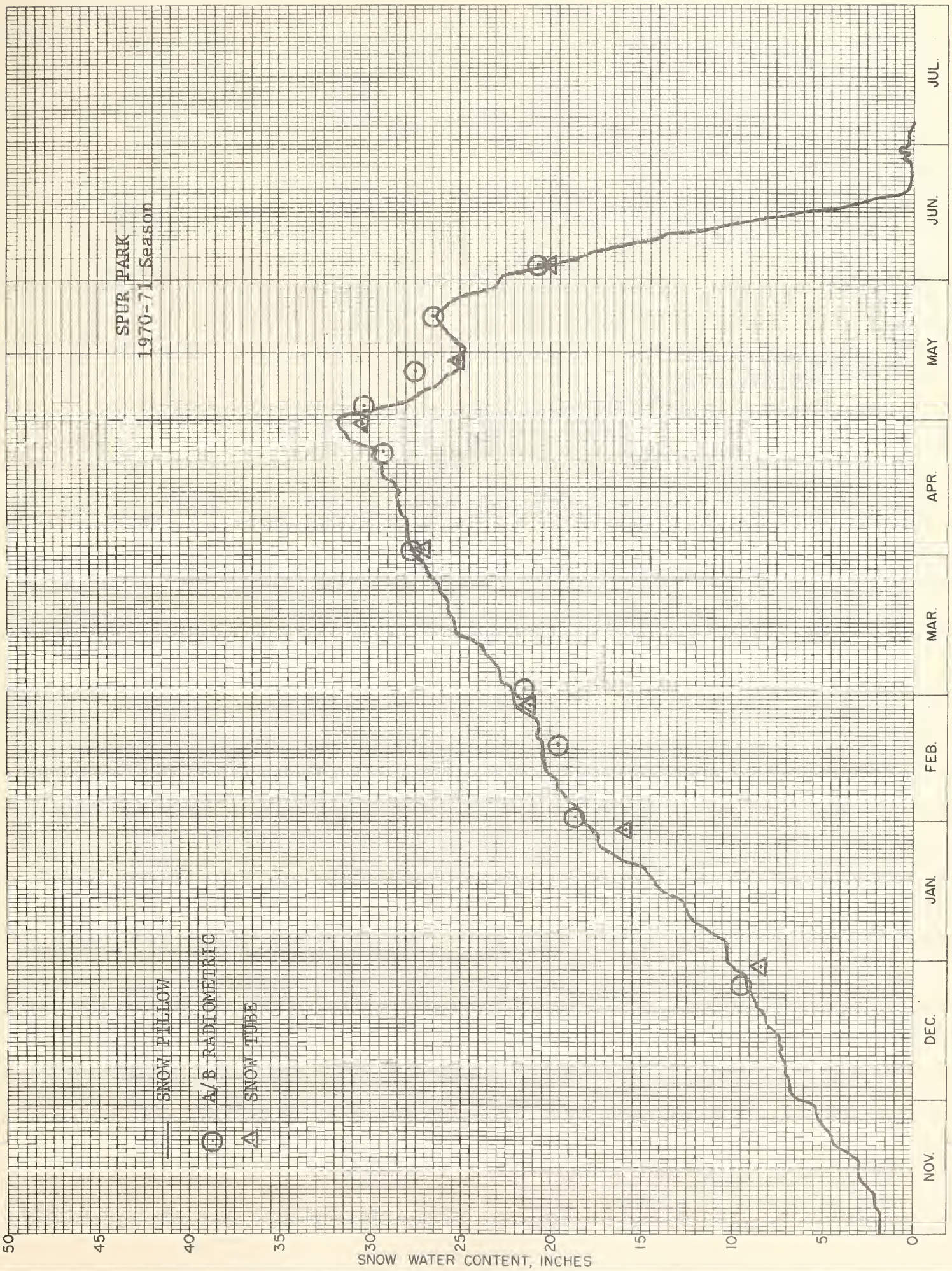
SPUR PARK
1970-71 Season
SNOW PILLOW
A/B RADIOMETRIC
SNOW TUBE
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
50
45
40
35
30
25
20
15
10
5
0
SNOW WATER CONTENT, INCHES

FIGURE 2.

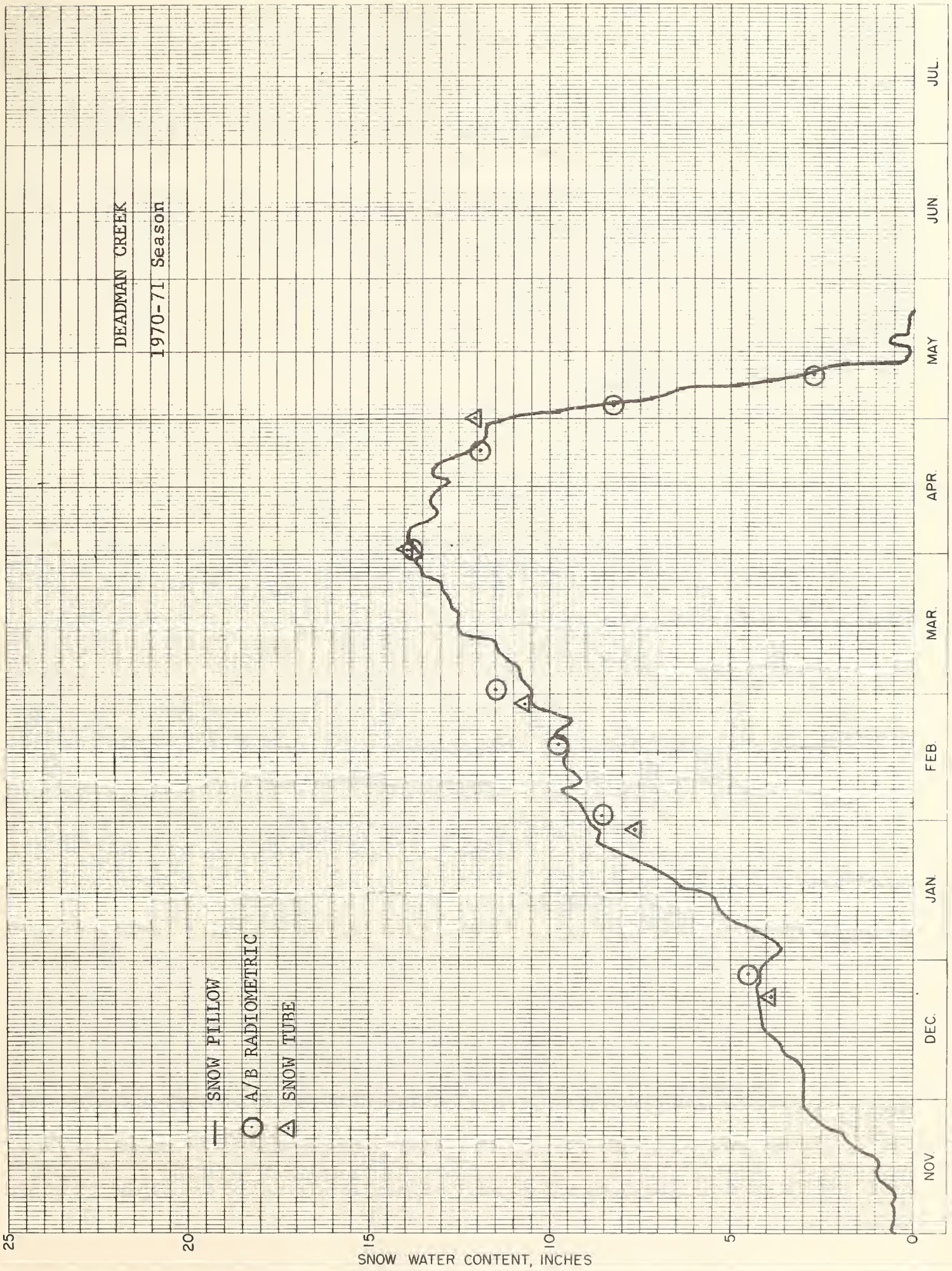
DEADMAN CREEK
1970-71 Season
SNOW PILLOW
A/B RADIOMETRIC
SNOW TUBE
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUN
JUL.
0
5
10
15
20
25
SNOW WATER CONTENT, INCHES

FIGURE 3.

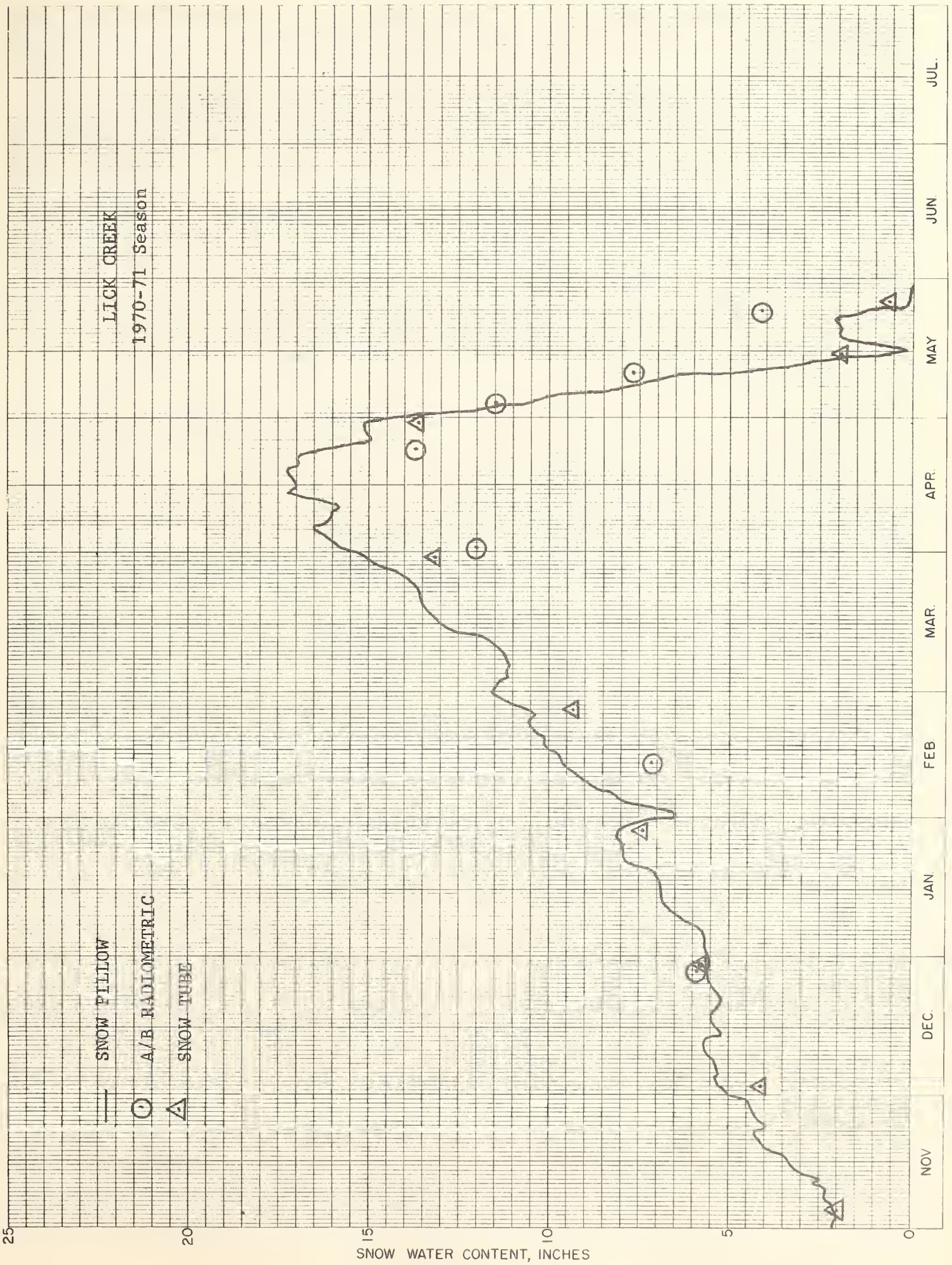
LICK CREEK
1970-71 Season
SNOW PILLOW
A/B RADIOMETRIC
SNOW TUBE
NOV
DEC.
JAN.
FEB
MAR.
APR.
MAY
JUN.
JUL.
25
20
15
10
5
0
SNOW WATER CONTENT, INCHES

FIGURE 4.

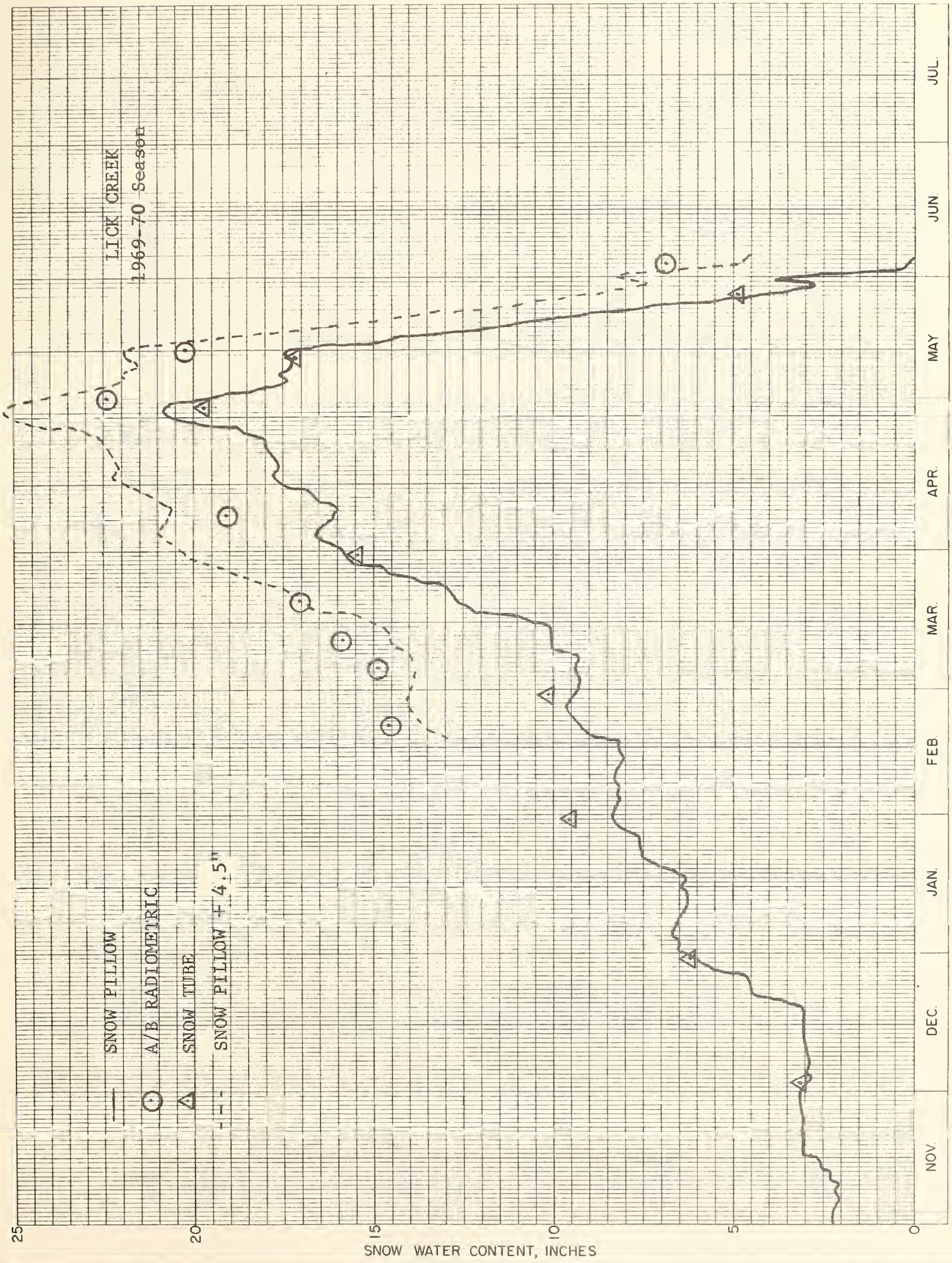
LICK CREEK
1969-70 Season
SNOW PILLOW
A/B RADIOMETRIC
SNOW TUBE
SNOW PILLOW + 4.5"
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
25
20
15
10
5
0
SNOW WATER CONTENT, INCHES

FIGURE 5.

TABLE I. Snow Water Equivalent, 1970-71 Season

Date	Spur Park Snow Pillow	Spur Park A/B	Spur Park Snow Course	Deadman Creek Snow Pillow	Deadman Creek A/B	Deadman Creek Snow Course	Lick Creek Snow Pillow	Lick Creek A/B	Lick Creek Snow Course
1970									
11/4							2.1		2.0
12/2							5.2		4.1
12/23				4.2		3.9			
12/26	9.1	9.5							
12/28				4.1	4.5		5.5	5.8	
12/29							5.4		5.7
12/30	9.9		8.3						
1971									
1/28							8.0		7.4
1/29	17.7		15.8	8.7		7.6			
2/1	18.1	18.6		8.9	8.6				
2/12							9.6	7.2	
2/17	20.4	19.5		9.5	9.7				
2/24							10.6		9.3
2/26	22.0		21.2	10.5		10.7			
3/1	22.1	21.5		10.5	11.5				
3/30							15.1		13.2
4/1	27.6	27.6	27.0	13.6	13.8	13.9	15.8	12.0	
4/23	29.5	29.3		12.2	11.9		16.3	13.7	
4/29							15.1		13.7
4/30	31.7		30.5	11.4		12.1			
5/3	29.0	30.4		8.8	8.3		10.7	11.5	
5/10	25.8	27.5		3.0	2.8		5.4	7.7	
5/13	25.5		25.1						
5/14							1.3		1.9
5/24	26.0	26.5					1.1	4.2	
5/26							0.1		0.7
6/3	20.1	20.6	20.2						

TABLE II. Snow Water Equivalent, 1969-70 Season
Lick Creek

Date	Snow Pillow	A/B	Snow Course
1969			
12/2	3.0		3.1
12/30	5.9		6.2
1970			
1/30	8.3		9.6
2/20	9.4	14.6	
2/27	9.4		10.2
3/5	9.4	14.9	
3/11	10.1	15.8	
3/20	12.7	17.1	
3/30	15.8		15.5
4/9	16.0	19.1	
5/2	20.7		19.7
5/4	19.6	22.4	
5/13	17.2		17.2
5/15	17.1	20.2	
5/27	4.4		4.9
6/3	0.2	6.9	

inches more water around the source than on the snow course. Figure 5 shows a displacement of 4.5 inches in the snow pillow records for comparison.

The no-snow count of July 1971 appears to have increased slightly over that taken in November 1970. This shift, when translated into water equivalent is not particularly large because of the exponential nature of the count vs. water relationship.

Likewise, the shift is not reflected in the data prior to June.

Degradation in detector resolution should reduce the observed count with time. Base line stability cannot shift because of an on-board source and spectrum stabilization, so scintillation equipment shifts may be ruled out.

It is concluded that the deficiency is in the data reduction and correction phase. Two additional factors, error in dead time determination, and air temperature corrections should be considered in computations. These are discussed further in this report.

Field Testing

The basic scintillation detection and pulse processing equipment is essentially that described in report RLO-2061-1. All worked well during the 1970-71 winter tests. An on-board calibration source showed virtually no count change from beginning to end of season, denoting stability of resolution and base line gain. This is essential to the A/B system.

A careful laboratory check was made March 29 to April 1 verifying spectrum checks of the previous November.

The final module, which is an electronic counter, is capable of resolving and recording separate counts for pulses spaced only 0.2 microsecond apart, but other restrictions in the system keep "resolving time" down to about 5 microseconds.

This was measured as accurately as possible in the laboratory using specially calibrated "dead time" sources. The dead time correction is shown in Table III. It can be seen that the count loss is small for rates of 5,000 counts/sec. or less, but the correction becomes large in the 10,000 to 50,000 counts/sec. region.

A field technique of using increased altitude to hold count rates to a reasonable value (1,500-2,000 counts/sec.) should be established, rather than relying solely upon a correction table. This is especially important in establishing zero count. Altitude was increased during the no-snow count this past season, but count rates of 30,000 were still encountered during the November and July zero flights.

An aluminum cover plate equivalent to approximately 3 inches water was used over the sources this year in the field. This was in contrast to the steel covers of previous tests. This and the high electronic bias point now being used virtually eliminated all undesirable curvature in the water attenuation line. (i.e., water depth vs. count rate). Discussion of "dose buildup" distortion is included in publication RLO-2061-1. This improvement simplifies computations.

TABLE III. Dead Time Loss

Assuming T = 5 μ sec.

R (Obs. Count)	R^2T R^2(5 μ sec.) (Loss)	R^* $R+R^2T$ (True Count)	$\frac{R^2T}{R^*}$ (i.e. % Loss)	Corr. $\frac{1}{(1-\%\ \text{Loss})}$
1.0K	5.0	1005	.0050	1.005
1.5K	11.25	1011	.0110	1.011
2.0K	20.0	2020	.0099	1.010
2.5K	31.25	2531	.0122	1.012
3.0K	45.0	3045	.0148	1.015
3.5K	61.25	3561	.0172	1.018
4.0K	80.00	4080	.0196	1.021
4.5K	101.25	4601	.0220	1.024
5.0K	125.00	5125	.0244	1.027
6.0K	180.00	6180	.0291	1.030
7.0K	245.00	7245	.0338	1.035
8.0K	320.00	8320	.0385	1.040
9.0K	405.00	9405	.0430	1.045
10.0K	500.00	10500	.0476	1.050
20.0K	2000.00	22000	.0909	1.100
30.0K	4500.00	34500	.1304	1.150
40.0K	8000.00	48000	.1667	1.200
50.0K	12500.00	62500	.2000	1.250

Ave. $\frac{\text{alt}}{146.7}$ = T in cone (for $\theta \cong 45^\circ$ and 100 mph)

$\frac{\text{Raw net}}{T}$ + 6K gnd/ sec. = maximum count rate (R)

It was possible to use the $e^{-\mu_n d}$ straight-line theoretical attenuation plot in producing the computed water equivalent values.

Computations

A sample data reduction form as used this past season is shown in Figure 6. Some revision is needed but this served quite well during the field testing.

Certain data corrections, mainly altitude and ground speed, must be applied to each pass, while others are more easily made to the entire body of data.

The $\mu_a h$ correction is the change in attenuation caused by the blanket of air between the source and aircraft. Small altitude changes from the nominal 100' could be ignored, but corrections need to be applied for altitude changes greater than $\pm$ 20'.

The "instrument correction" is a dead-time correction.

A correction which was not considered, but should be, is compensation for the effect of temperature on the intervening air blanket. It is small if one considers only wintertime temperature.

Discussions with Mr. E. L. Peck, National Weather Service, indicate this correction should be considered.

The November no-snow flights and the June-July no-snow flights were taken at some 50° - 60° F. difference in mean air temperature. Calculations show that the final zero offset which occurred during this testing could be in the order of an 8-10 percent correction in final net count. This may also explain some smaller midseason variations

Flight _____ Date _____ Snow Course _____ Job _____

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		in feet	in feet	$\frac{(f)(\text{mkr sep gnd})}{(\text{mkr sep photo})}$	above source in feet	from photo with known altitude (in feet)	in photo of unk altitude where mkrs are missing	col 5 + col 6 - or - $alt_x = alt_a(dia_a)/dia_x$	in seconds	any object measured at gnd surface	from flight log	alt/100	$\frac{(\text{alt})(\text{photo travel})}{(f)(\text{exp int})(1.4667)}$	from sep table	multiply cols. 12,13,14,15
pass	exp	mkr sep photo	mkr sep gnd	alt above mkr	mkr ht	ref obj dia a	ref obj dia x	alt	exp int	photo travel	raw net count	alt corr	gnd speed corr	$\mu_a h$ corr	corr net count

NOTES:
f of lens = _____ ft.

Ave. corrected net count	
Snow course elev corr	
Decay corr	
Instrument or misc corr	
Final net count	
Water equivalent	

FIGURE 6. Data Reduction Form.

which occur, although midwinter altitudes in the order of 100' are being used.

In the future, altitudes of 400' to 600' may be used for zero or shallow water flights, necessitating correction for temperature effect.

Conclusions and Recommendations

The system appears ready for field use.

The system can be used for absolute measurement and does not require ground visitation cross-checks to establish the count vs. water equivalent attenuation line if cask is installed and backfilled prior to the beginning of permanent snowpack accumulation. Its accuracy is generally comparable to the Federal snow sampler. Certain features need refinement.

1. Camera dependability needs improvement. The K24 appears suitable but needs modification. It would be desirable if all equipment could be placed within reach of the operator rather than in a belly pod. This may or may not be economically feasible. Most malfunctions however could be solved by some on-board trouble shooting. A "Sonalert" should be installed to warn of film transport malfunction.
2. Camera trigger interval should be established by a digital intervalometer rather than the RC network type presently being used. This would increase confidence in the ground speed correction.

3. A reliable thermometer should be carried in the aircraft to obtain temperature that can be used to apply correction to the data.
4. A rapid response, count rate meter should be added to the instrument control panel. It could be "red lined" to aid the operator in making decisions regarding changing altitude and preventing excessive instrument "dead-time" or count rate overloading. Depending upon its accuracy, its readings may conceivably be used directly in the data reduction process if it could have a "hold" circuit for maximum reading.
5. A rework of the "data reduction" sheet with an expansion of certain tables would be desirable. A computer program should be developed to handle the direct calculations.
6. The cask scatter plate design and capping procedure for the ground site emplacements needs improvement. This would minimize risk during leak testing and eventual removal of the cask from a ground site. A small portable trolley arrangement could be used to lower a shield disc over the source from a remote position.

The present installation is not too hazardous, but subsequent retrieval has proved more difficult since backfilling makes the cask difficult to raise to a safe working height.

Economics

Cost estimates are shown on pages 75, 76 and 77 of publication RLO-2061-1. These figures appear to be reasonable, based on the 1970-71 field experiences.

These pages have been reproduced as pages 18, 19 and 20 of this report.

CAPITAL INVESTMENT PER GROUND EMPLACEMENT
A/B SYSTEM

Type A: 45"-60" snowpack; to 20" water equivalent			
chain link, 12' high x 16' square	143.00		
barbed wire, brackets	15.00		
cement, posts 7 pad	5.00		
aerial markers	32.00		
2 x 8 headers	10.00		
labor - 6 man-days	240.00		
Enclosure Sub-total		$ 465.00	
source 3C Cs^{137}	305.00		
freight @ 13.00/cwt/R.T.	16.00		
eventual disposal fee, freight	80.00		
Source Sub-total		$ 401.00	
cask materials	90.00		
cask labor	100.00		
Cask Sub-total		$ 190.00	
TOTAL COST PER SITE - - - - - - - - - - - -			$1,056.00
Type B: 90" snowpack; 20"-30" water equivalent			
chain link, 14' high x 20' square	240.00		
other fence materials and markers	63.00		
labor - 8 man-days	320.00		
Enclosure Sub-total		$ 623.00	
source: 30 C Cs^{137}	1,050.00		
freight: 200# @ 13.00/cwt	26.00		
eventual disposal fee, freight	80.00		
Source Sub-total		$1,156.00	
cask materials	100.00		
cask labor	100.00		
Cask Sub-total		$ 200.00	
TOTAL COST PER SITE - - - - - - - - - - - -			$1,979.00
Type C: 120" snowpack; 30"-40" water equivalent			
chain link, 16' high x 26' square	340.00		
other fence materials and markers	63.00		
labor - 10 man-days	400.00		
Enclosure Sub-total		$ 803.00	
source: 34 C Co^{60}	710.00		
freight: 1100# @ 13.00/cwt	143.00		
eventual disposal fee, freight	125.00		
Source Sub-total		$ 978.00	

(From publication RLO-2061-1)

Type C: continued

helicopter installation		$ 200.00	
cask materials	150.00		
cask labor	150.00		
Cask Sub-total		$ 300.00	
TOTAL COST PER SITE - - - - - - - - - - - - - -			$2,281.00

Note: Depreciation of Co^{60} on same basis as Cs^{137}; plan to move source to new location with less water equivalent. This source is twice the activity required so can be left 7.5 years.

Type D: 144" snowpack; 40"-48" water equivalent

chain link, 18' high x 30' square	450.00		
fence materials and markers	70.00		
labor - 10 man-days	400.00		
Enclosure Sub-total		$ 920.00	
source: 60 C Co^{60}	1,100.00		
freight: 1200# @ 13.00/cwt	156.00		
eventual disposal fee, freight	125.00		
Source Sub-total		$1,381.00	
helicopter installation		$ 200.00	
cask materials	175.00		
cask labor	150.00		
Cask Sub-total		$ 325.00	
TOTAL COST PER SITE - - - - - - - - - - - - - -			$2,826.00

Note: This source must be moved in 2-3 years, creating some logistics problems.

The above isotope costs are based on the following quotes:

Co^{60}: $15/Curie + $200 encapsulating

Cs^{137}: $35/Curie + $200 encapsulating

AIRCRAFT: electronics and pod as listed in Sec. IX.

electronics and camera	$5,800.00	
aircraft pod	665.00	
A/B Instruments		$6,465.00

(From publication RLO-2061-1)

ANNUAL COSTS

(per average site)

A/B Radiometric

	Cost	Average	Dep. Period Years	Annual Cost Station
Capital depreciation/year:				
ground emplacement				
14 x Type A				
23 x Type B				
5 x Type C				
5 x Type D				
÷ 47 stations	85,836 / 47	1,826	15	$ 122.00
electronics	6,465 / 47	138	5	28.00
Leak testing source (1)		80	1	80.00
Aircraft & pilot (2) 47 courses 4 flts/course, $11/flt.		44	1	44.00
Operating supplies:				
film and chemicals		12	1	12.00
maintenance-field (3)	2,538 / 47	54	1	54.00
Labor:				
10 man-months includes data reduction	4,794 / 47	(Cost per snow course per year for 4 flights)		102.00
				$ 442.00

(1) Radiation Sources Committee (MSU) quotes $100.00/source. This is considered high for an annual leak test and should be negotiated for a quantity basis.

(2) This figure is based on a flight plan which includes approximately six courses per flight and these reduce ferry time attributable to each course. At present only one course can be flown per flight.

(3) Total annual maintenance - 6th year on - estimated at $2,500/year.

(From publication RLO-2061-1)